# Advanced Reflectance Standards for Monitoring Climate Change Forces

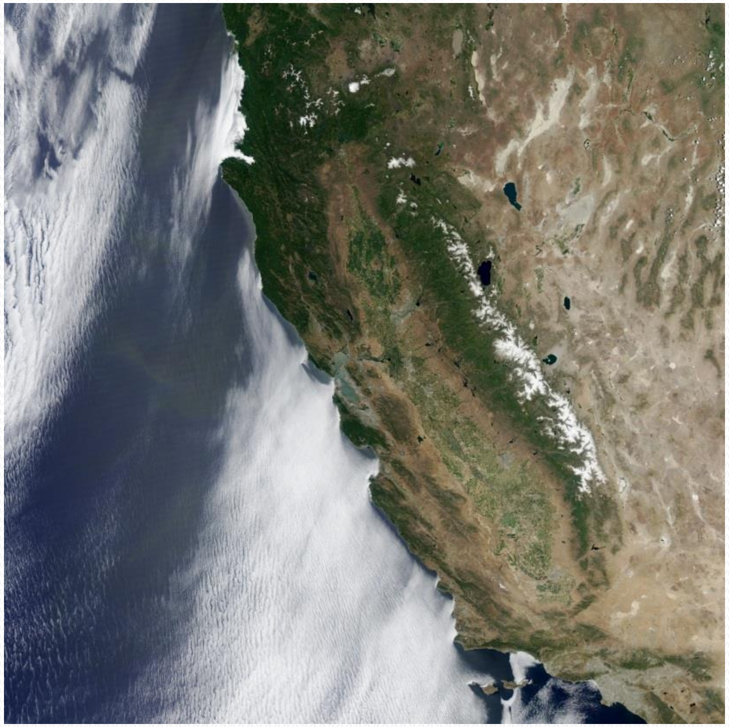
Heather Patrick, David Allen, Catherine Cooksey, Thomas Germer, Joseph Rice, and Benjamin Tsai
National Institute of Standards and Technology
Gaithersburg, MD 20899 USA

# Reflectance and Climate Science

**Why is Reflectance Important?**

- Overall Earth Albedo (reflectance) important in determining net warming or cooling due to solar radiation
  - High albedo: snow, cloud cover
  - Low albedo: forest, dark pavement
  - Angle dependent albedo: water
- Spectral composition of Albedo used in
  - Atmosphere: water vapor, cloud properties, aerosols
  - Ecology: chlorophyll, leaf water, pigments
  - Geology: mineral and soil types
  - Coastal Waters: chlorophyll, phytoplankton, organic materials and sediments
  - Snow/Ice: snow cover fraction, grain size, melting
  - Biomass Burning: smoke, fires
  - Commercial: mineral exploration, agriculture, forest production

earthobservatory.nasa.gov

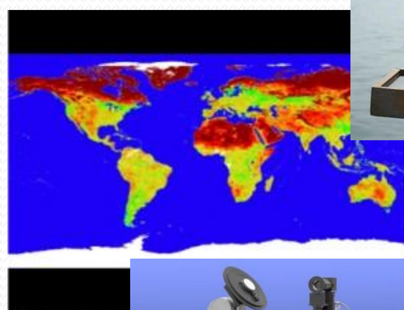


**NIST's role:**

- Disseminating reflectance scale
- Insuring SI traceability of reflectance measurements
- Providing techniques, models and tools for remote sensing community

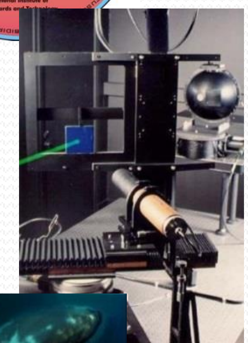
# Objectives

SCATMECH for modeling materials and scattering



Calibration and use of reflectance standards: STARR


New facilities: ROSI and hyperspectral imaging/projection



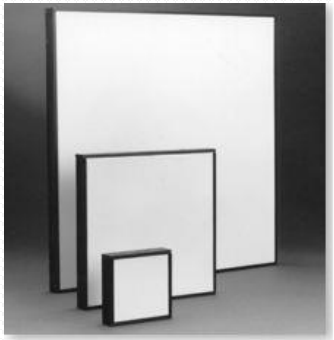

To facilitate the monitoring of climate change forces through:

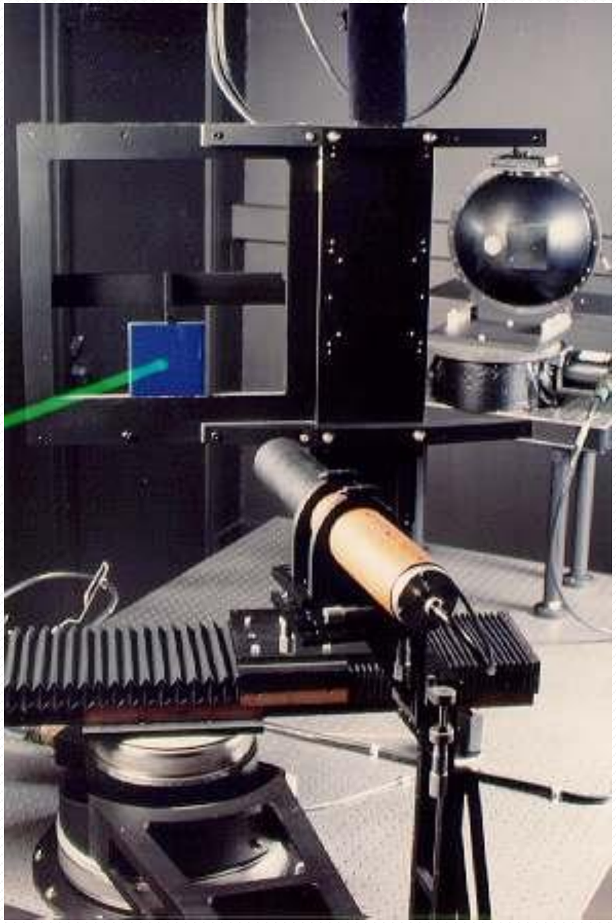
- Dissemination of the reflectance scale
- Improved capabilities for the characterization of reflective and scattering materials
- Improved theoretical understanding of reflective and scattering materials

# Dissemination of the Reflectance Scale

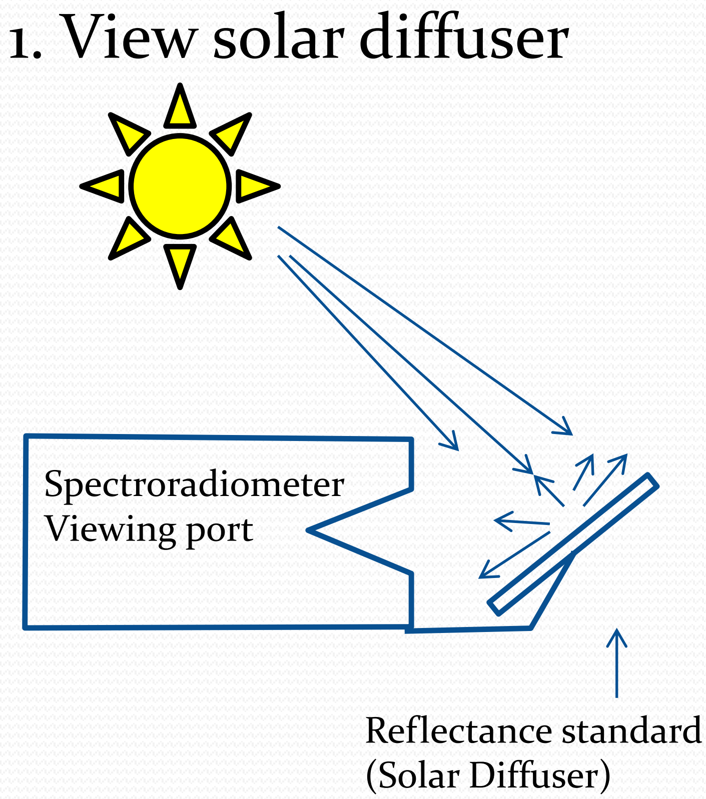
# Spectral Tri-function Automated Reference Reflectometer (STARR)

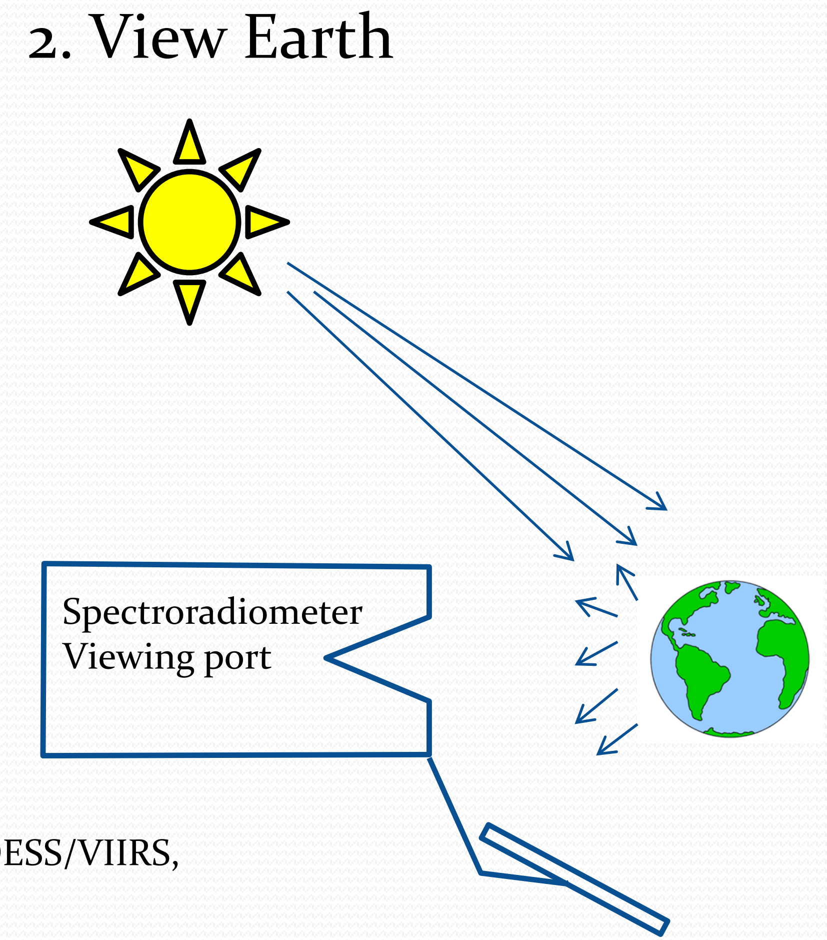
- Primary source of reflectance calibrations for US for nearly 20 years
- Disseminate scale through calibration of reflectance standards
  - Yearly calibration of standards for NASA/GSFC
  - Provides traceability to diffusers used in satellites
- Three measurement geometries :
  - Directional-hemispherical (250 nm to 2500 nm)
  - Specular (250 nm to 2500 nm)
  - In-plane, bidirectional (250 nm to 1100 nm*)





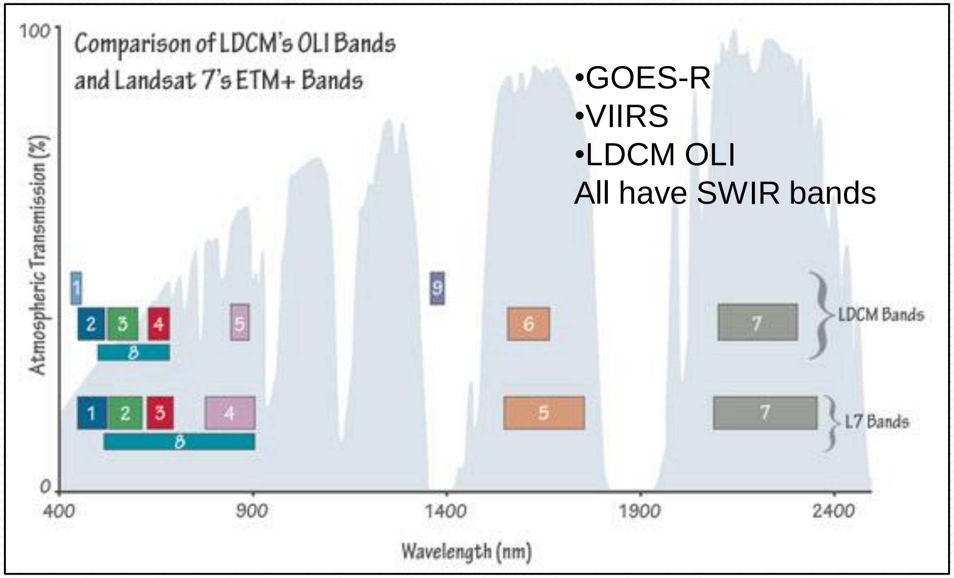
# Use of Reflectance Standards: On-orbit

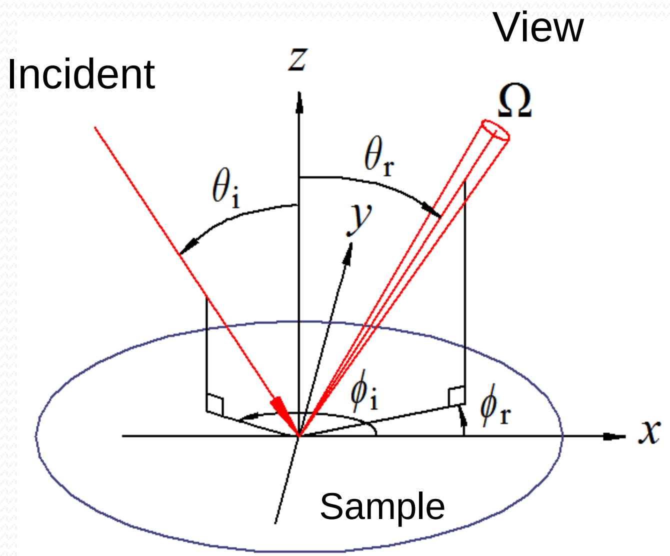



- Solar diffuser on satellite (MODIS, LDCM, NPOESS/VIIRS, CLARREO…)
- Compare earth radiance to diffuser radiance, Sun as common source
- Part of calibration/validation for satellite spectroradiometer

# Meeting Research Challenges




*STARR: in-plane only ($\phi_i$ = 180° and $\phi_r$ = 0°)*
*ROSI: out-of-plane, any combination of $\theta_i$, $\phi_i$, $\theta_r$ and $\phi_r$*

**Research Challenges**

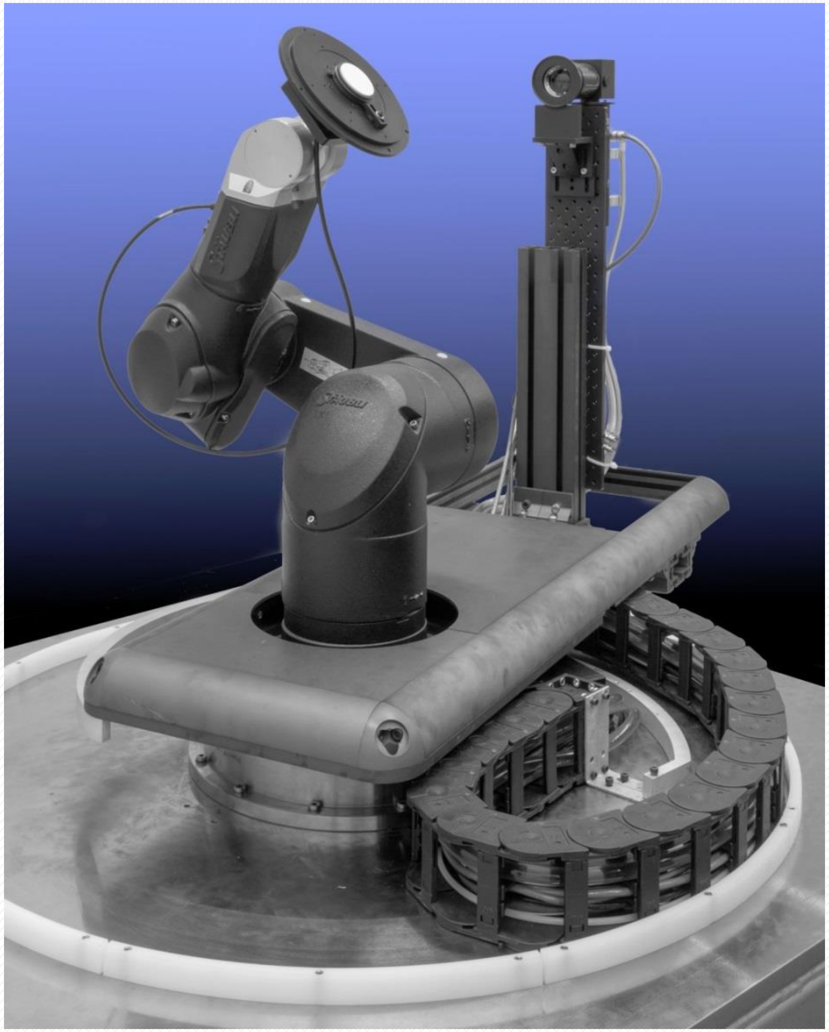
- **Spectral range**: growing need to cover the full solar reflective region
  - In the past, bidirectional measurements beyond 1100 nm for STARR limited by availability of detectors with sufficient signal-to-noise ratio and linearity
- **Out-of-plane geometries** to match use of standards in practice

**Research Approach**

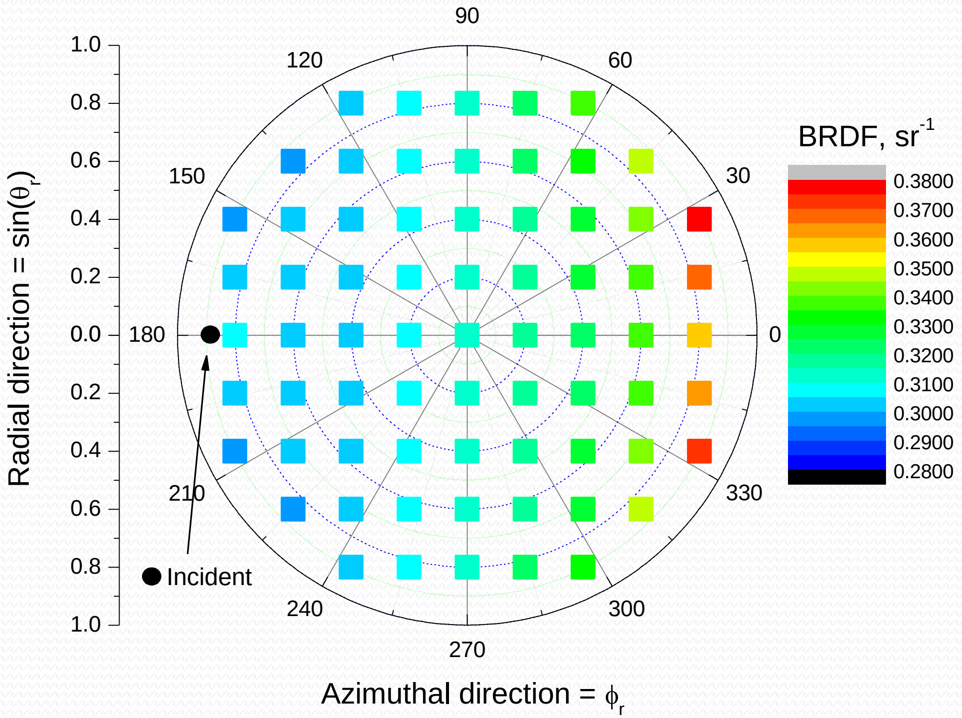
- ✓ Expand STARR measurement capability from 1100 nm to 2500 nm for 0/45 geometry using low noise, 4-stage ex-InGaAs detector
- ○ ROSI: next-generation reference reflectometer with multi-angle, out-of-plane measurement capability

# Robotic Optical Scatter Instrument (ROSI)

- New facility for multi-angle spectral reflectance
- Currently 480 nm to 2500 nm tunable operation, with wavelengths to 250 nm integrated fall 2014
- Full out-of-plane capabilities
- Improved sample handling
- Simultaneous operation of silicon (UV-NIR) and ExInGaAS (SWIR) detectors

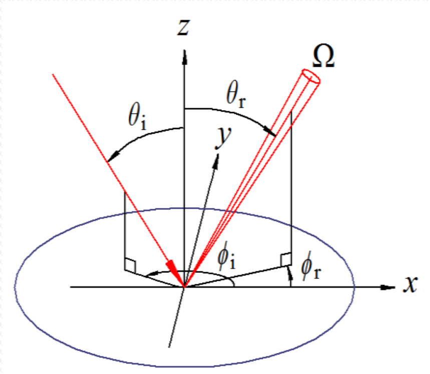


# Hemispherically-scanned viewing with ROSI




Fixed incident at
$\theta_i = 60°$ and $\phi_i = 180°$

Vary view angles
both $\theta_r$ and $\phi_r$



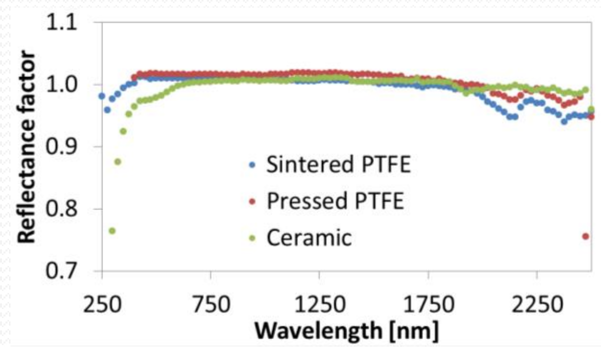

- BRDF varies with polar ($\theta_r$) and azimuthal ($\phi_r$) viewing angles
- At fixed $\theta_r$, BRDF varies with $\phi_r$
  - In-plane view $\theta_r = 36.9°$ $\phi_r = 0°$, ($x = 0.6$, $y = 0$), BRDF = 0.3367 $sr^{-1}$
  - Rotate view 90° $\theta_r = 36.9°$ $\phi_r = -90°$ ($x = 0$, $y = -0.6$) BRDF = 0.3122 $sr^{-1}$
- Illustrates the need to calibrate samples in geometry that will be used by customer!

# Research Focus Areas

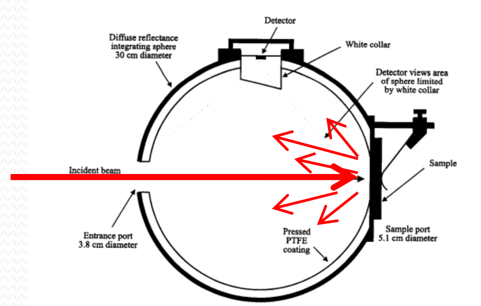
- UV-induced reflectance changes
  - Reflectors subject to UV i.e., during space flight
  - Limited knowledge of effect
  - NIST SPHERE collaboration on UV aging

NIST SPHERE (Simulated Photodegradation by High Energy Exposure) http://www.nist.gov/el/facilities_instruments/integrating_sphere_fac.cfm

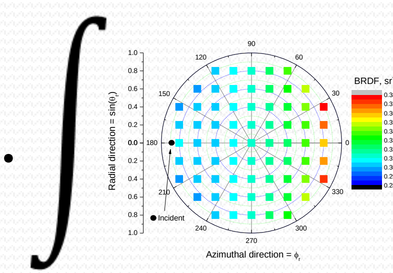
- Enhanced standards
  - New materials
  - Flatter spectral response, durability, etc.
  - Publish broader spectral range for 0:45 pressed PTFE




- Validation hemispherical reflectance using multiple methods
  - Compare sphere-based and integrated angle-scanning methods
  - Update reference values
  - Increased confidence and lower uncertainties



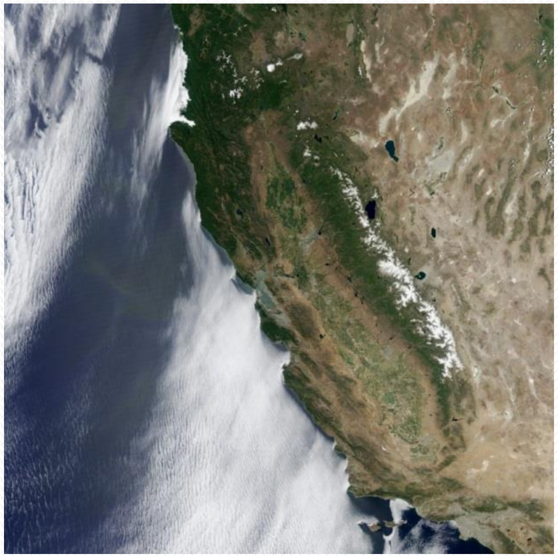

VS.



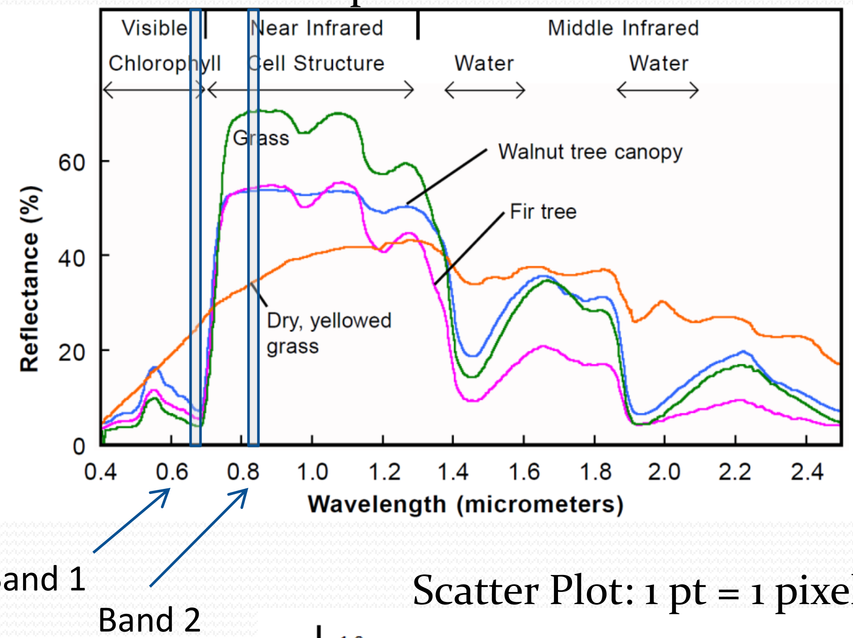
# Improved Capabilities for the Characterization of Reflective and Scattering Materials

- Robotic Optical Scatter Instrument (ROSI)
- Hyperspectral Imaging Microscope
- Hyperspectral Image Projector (HIP)

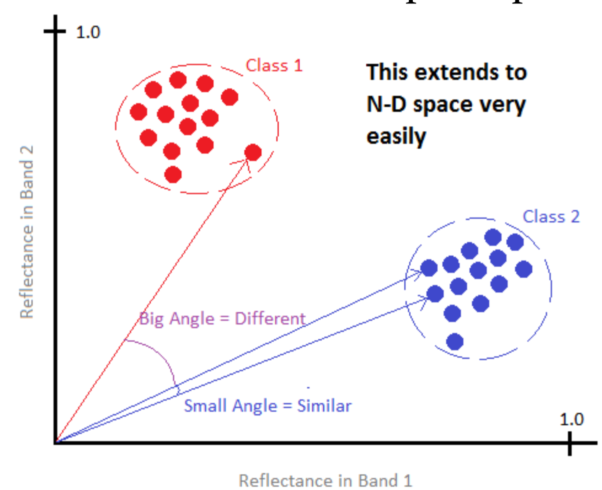
# What is hyperspectral imaging?



Spectrum Plot




Scatter Plot: 1 pt = 1 pixel




- Hyperspectral imagers give a spectrum for each pixel
- Resolution matters
- Simplify classification of pixels by grouping into those with like reflectance combinations
  - Easy to visualize in 2-D
  - Hyperspectral "n-D" improves differentiation of components
- Use to estimate biomass, vegetation health, leaf water, etc.
- Many algorithms exist
- Accuracy of algorithms difficult to quantify

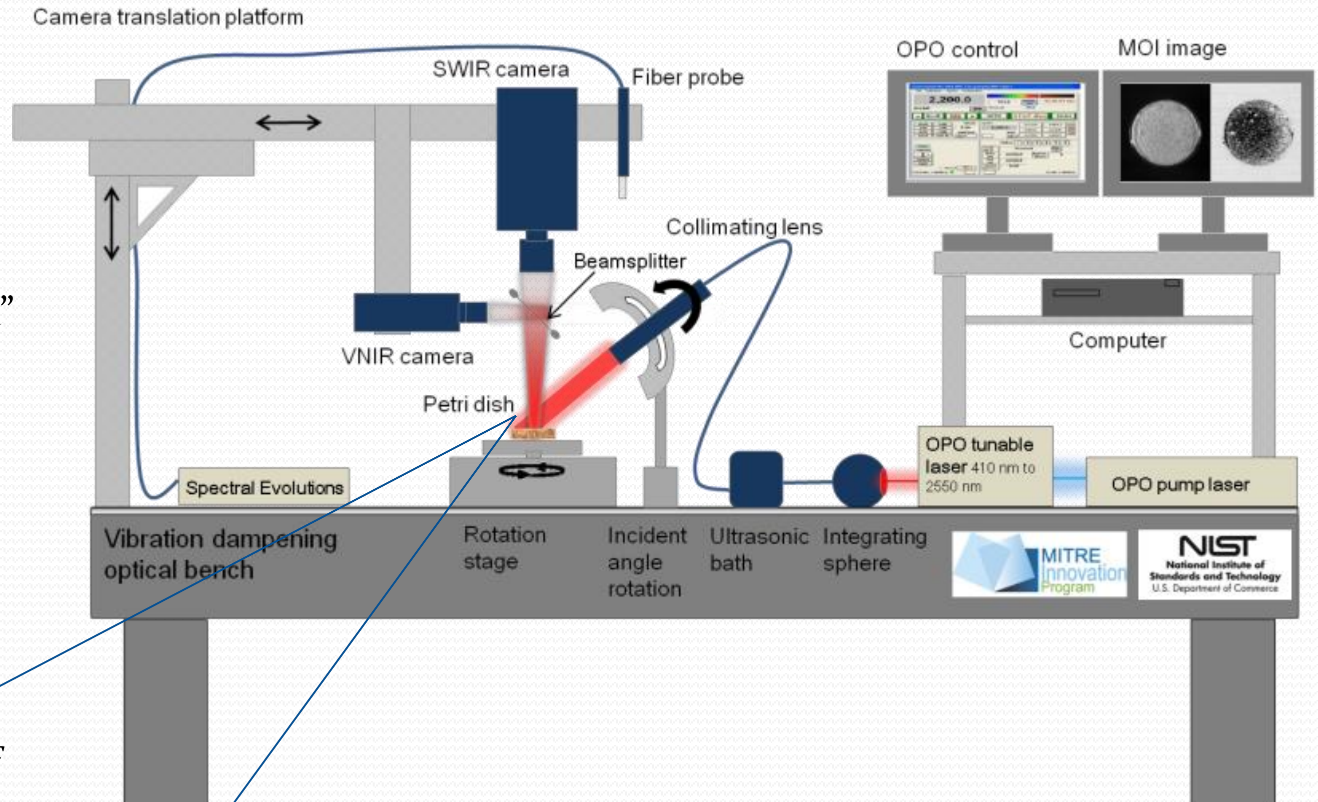
# NIST OPO based hyperspectral imaging microscope

## Research Challenge

- Validating pixel classification algorithms
- Ability to produce scenes with known “ground-truth” and measure their spectral signatures

## Research Approach

- Assemble microscenes with known components
- Measure microscene spectra with hyperspectral microscope
- Use HSI microscope to develop standard datasets and evaluate performance of algorithms on known scenes




- Broadband camera views sample under a microscope
- Tunable laser (Optical Parametric Oscillator - OPO) illuminates sample
- A reflectance image is collected at each wavelength, from 405 nm to 2500 nm
- The resulting high resolution data cube can be representative of materials viewed by remote-sensing hyperspectral imagers in the field

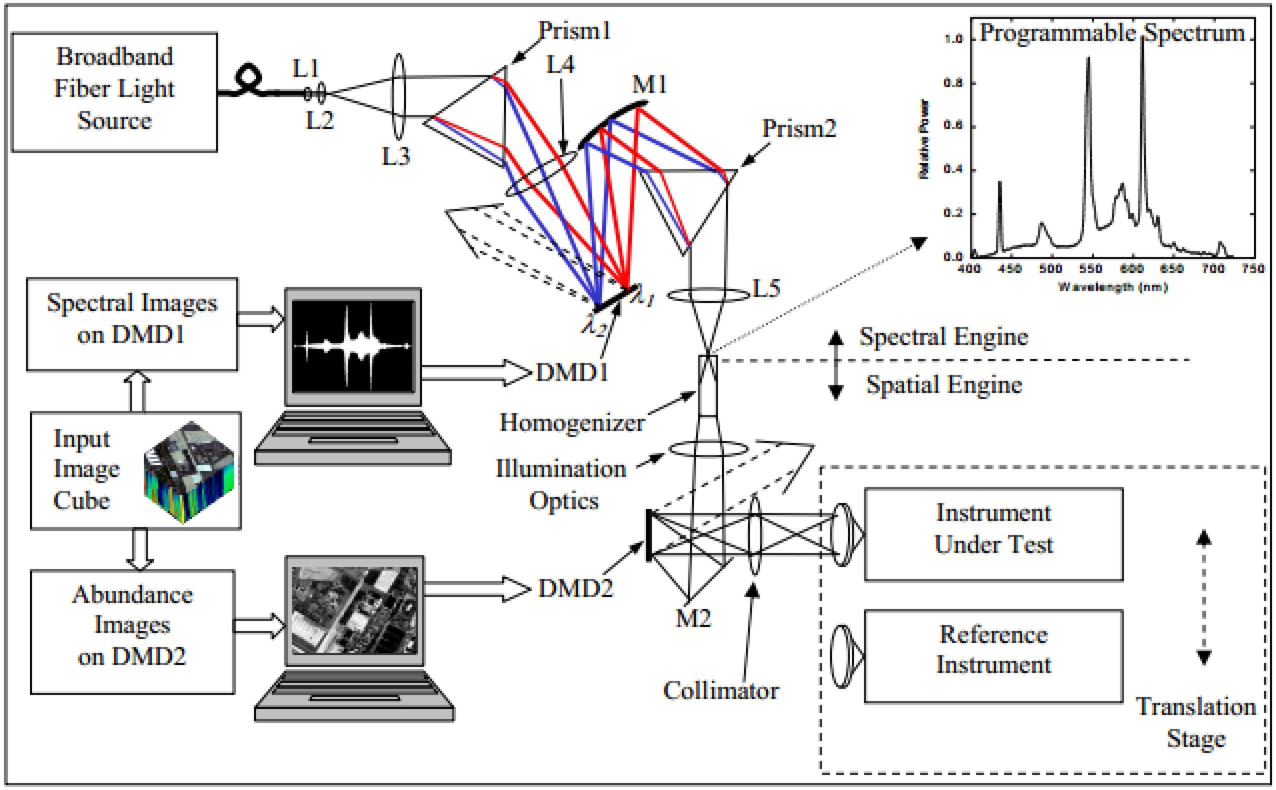
# NIST Hyperspectral Image Projector (HIP)

**Research Challenge**

- Need to provide changing, realistic scenes for testing imagers in a laboratory environment

**Research Approach**

- Use airborne hyperspectral images and/or microscene hyperspectral images as input cube
- Project using HIP
- Use to help validate biomass estimators using projected scenes
- Potential calibration service for hyperspectral imagers





Original and HIP-projected images of a coral reef

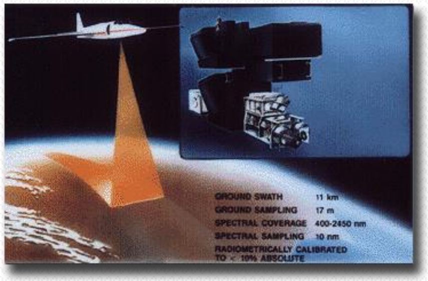
# Desired Future Outcomes

## From the Hyperspectral Microscope:

- Validation of biomass-data retrieval algorithms by using known/standard scenes
- Reference spectral data sets for biomass materials with measured spectral distributions

## From the Hyperspectral Image Projector (HIP):

- Validation of biomass data as retrieved from sensor/algorithms by using projected scenes
- Capability to provide performance testing of hyperspectral imaging systems
    - such as AVIRIS and HyspIRI (see below)
- Calibration service for hyperspectral imagers




Airborne Visible/Infrared Imaging Spectrometer (AVIRIS)
- Existing aircraft-based hyperspectral imager
- http://aviris.jpl.nasa.gov/

Hyperspectral InfraRed Imager (HyspIRI)
- Future satellite-based hyperspectral imager
- Will enable global biomass surveys of land vegetation
- http://hyspiri.jpl.nasa.gov/

# Improved theoretical understanding of reflective and scattering materials

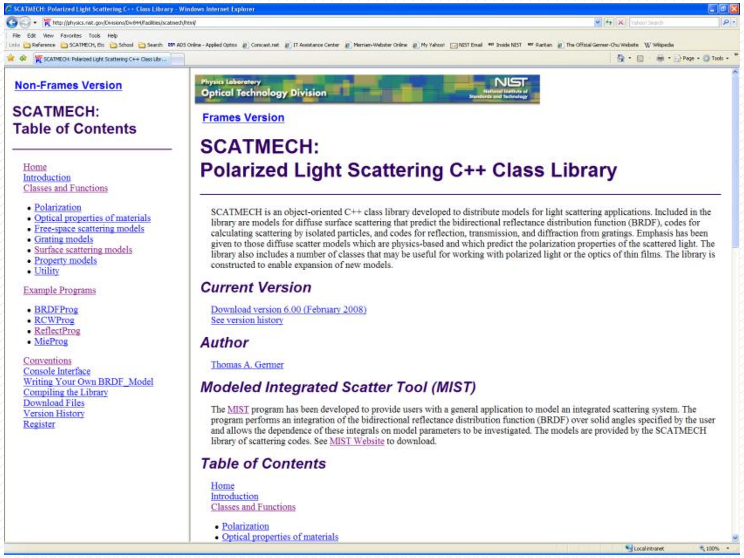
# SCATMECH: Polarized Light Scattering C++ Class Library

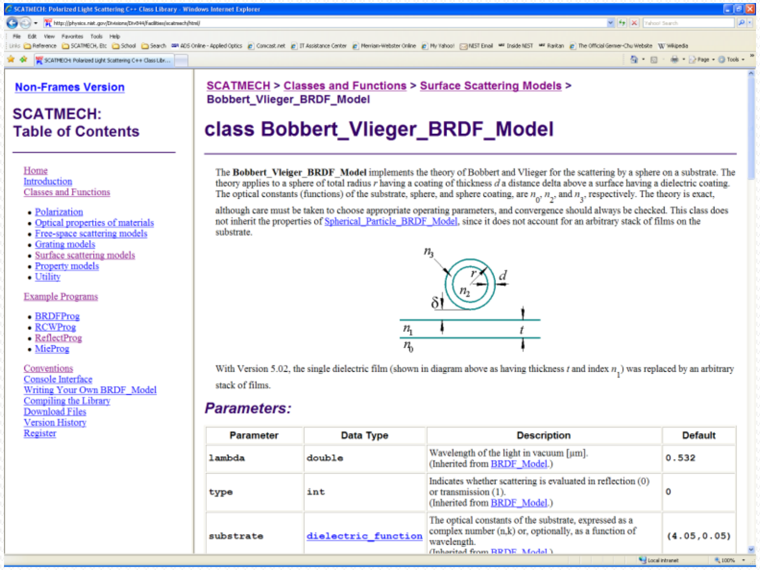
http://pml.nist.gov/scatmech

Software library provides tools for light scattering calculations, including:

- Polarization
- Optical properties of materials
- Thin film optics
- Optical scatter models (23)
- Diffraction grating models

Library is free and in the public domain.



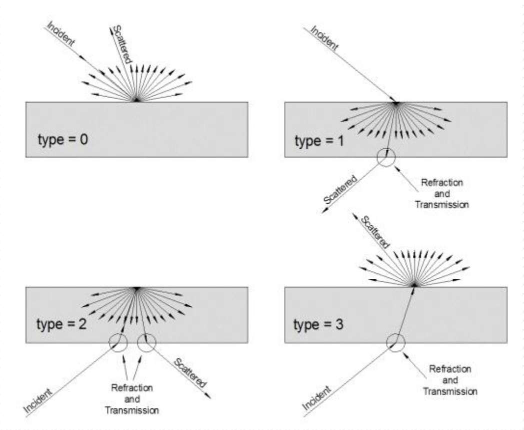

Library is designed to work with larger programs for ray tracing, image rendering, and simulation.

Socket for light scattering models enables others to add models without modifying SCATMECH or user program.

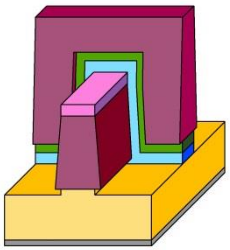
Current version: 6.01 (May 2008)

# SCATMECH Version 7

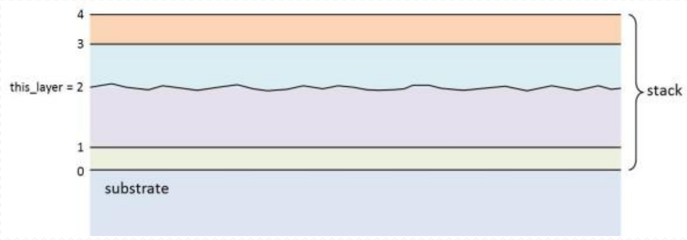
- Planned release Fall 2014
- New features:
  - Most BRDF models will have transmission and upwelling modes.



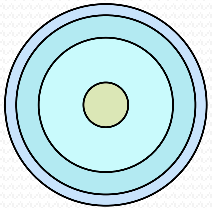

  - Rigorous coupled wave analysis for 2D gratings



  - Enhanced codes for scattering in multilayer dielectric coatings.



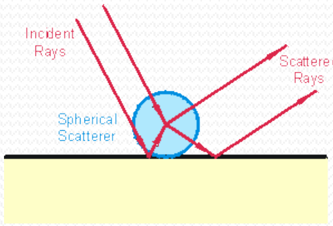

  - Multilayer-coating Mie scattering



# SCATMECH Applications

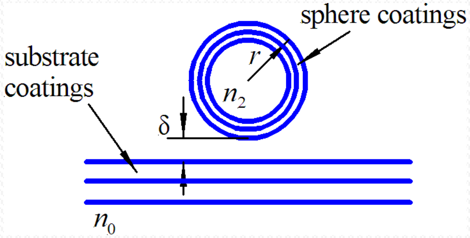
- Many models are valid in specific limits:
  - Roughness in the smooth surface limit
  - Roughness in the facet approximation
  - Volume scattering
  - Particle scattering

  *These codes are useful for estimating scatter levels in optics, appearance modeling, material characterization, etc.*

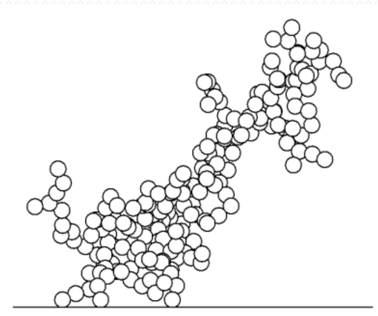



- Some give “exact” solutions to Maxwell’s equations
  - Sphere on a surface
  - Sphere in free space (Mie scattering)
  - Binary gratings

  *Used for metrology applications: dimensional metrology benchmarks for more general (finite element, FDTD, etc.) codes*




- Future models in development
  - Fractal aggregated clusters in aerosol and on surfaces
  - Radiative transfer in highly diffuse anisotropic materials (such as skin or clouds with aligned ice crystals)



# Summary and Future Challenges

# Summary

- Supporting future needs for traceability and reflectance dissemination through materials studies and expansion of reflectance capabilities
- Commissioning of ROSI facility and comparisons of 0:45 bidirectional reflectance with STARR underway
- Recent installation of Hyperspectral microscopy facility and use of HIP expanding capabilities to increase accuracy in biomass estimation and other remote sensing data products
- SCATMECH provides tools for calculation of light scattering for metrology and materials characterization

# Future Challenges

- Enhanced materials for reflectance standards and meeting customer needs for expanded calibration wavelengths and geometries
- Establishing accuracy in remote sensing biomass algorithms
- Capabilities for performance testing of hyperspectral remote sensing systems
- Model development for clusters in aerosols and on surfaces

# Acknowledgements and Links

Clarence Zarobila

Christopher White, Eric Byrd, and Deborah Stanley

Ronald Resmini, Robert Rand, Christopher Deloye, Jeffrey Stevens

Spectrophotometry short course:
http://www.nist.gov/pml/div685/sc/spectrophotometry_course.cfm
*Spectrophotometry: Accurate Measurement of Optical Properties of Materials,* Thomas A. Germer, Joanne C. Zwinkels, and Benjamin K. Tsai, Eds., Volume 46 in *Experimental Methods in the Physical Sciences* (Academic Press, New York, 2014).

http://www.nist.gov/pml/div685/grp03/spectrophotometry_starr.cfm

http://www.nist.gov/pml/div685/grp06/starr2.cfm

http://www.nist.gov/pml/div685/grp04/hip.cfm

http://www.nist.gov/pml/div685/grp06/scattering_scatmech.cfm

# Thank you!